Method and Apparatus for Estimating a Maximum Rate of Data and for Estimating Power Required for Transmission of Data at a Rate of Data in a Communication System

BACKGROUND

Field

[1001] The present invention relates generally to communication systems, and more specifically to a method and an apparatus for estimating a reverse link maximum data rate and for estimating power required for transmission of a data at a rate of data in a communication system.

Background

[1002] Communication systems have been developed to allow transmission of information signals from an origination station to a physically distinct destination station. In transmitting information signal from the origination station over a communication channel, the information signal is first converted into a form suitable for efficient transmission over the communication channel. Conversion, or modulation, of the information signal involves varying a parameter of a carrier wave in accordance with the information signal in such a way that the spectrum of the resulting modulated carrier is confined within the communication channel bandwidth. At the destination station the original information signal is reconstructed from the modulated carrier wave received over the communication channel. In general, such a reconstruction is achieved by using an inverse of the modulation process employed by the origination station.

[1003] Modulation also facilitates multiple-access, i.e., simultaneous transmission and/or reception, of several signals over a common communication channel. Multiple-access communication systems often include a plurality of remote subscriber units requiring intermittent service of relatively

short duration rather than continuous access to the common communication channel. Several multiple-access techniques are known in the art, such as time division multiple-access (TDMA) and a frequency division multiple-access (FDMA). Another type of a multiple-access technique is a code division multiple-access (CDMA) spread spectrum system that conforms to the "TIA/EIA/IS-95 Mobile Station-Base Station Compatibility Standard for Dual-Mode Wide-Band Spread Spectrum Cellular System," hereinafter referred to as the IS-95 standard. The use of CDMA techniques in a multiple-access communication system is disclosed in U.S. Patent No. 4,901,307, entitled "SPREAD SPECTRUM MULTIPLE-ACCESS COMMUNICATION SYSTEM USING SATELLITE OR TERRESTRIAL REPEATERS," and U.S. Patent No. 5,103,459, entitled "SYSTEM AND METHOD FOR GENERATING WAVEFORMS IN A CDMA CELLULAR TELEPHONE SYSTEM," both assigned to the assignee of the present invention.

[1004] A multiple-access communication system may be a wireless or wire-line and may carry voice and/or data. An example of a communication system carrying both voice and data is a system in accordance with the IS-95 standard, which specifies transmitting voice and data over the communication channel. A method for transmitting data in code channel frames of fixed size is described in detail in U.S. Patent No. 5,504,773, entitled "METHOD AND APPARATUS FOR THE FORMATTING OF DATA FOR TRANSMISSION", assigned to the assignee of the present invention. In accordance with the IS-95 standard, the data or voice is partitioned into code channel frames that are 20 milliseconds wide with data rates as high as 14.4 Kbps. Additional examples of a communication systems carrying both voice and data comprise communication systems conforming to the "3rd Generation Partnership Project" (3GPP), embodied in a set of documents including Document Nos. 3G TS 25.211, 3G TS 25.212, 3G TS 25.213, and 3G TS 25.214 (the W-CDMA standard), or "TR-45.5 Physical Layer Standard for cdma2000 Spread Spectrum Systems" (the IS-2000 standard).

[1005] In a multiple-access communication system, communications between users are conducted through one or more base stations. A first user on one subscriber station communicates to a second user on a second subscriber station by transmitting data on a reverse link to a base

station. The base station receives the data and can route the data to another base station. The data is transmitted on a forward link of the same base station, or the other base station, to the second subscriber station. The forward link refers to transmission from a base station to a subscriber station and the reverse link refers to transmission from a subscriber station to a base station. Likewise, the communication can be conducted between a first user on one mobile subscriber station and a second user on a landline station. A base station receives the data from the user on a reverse link, and routes the data through a public switched telephone network (PSTN) to the second user. In many communication systems, e.g., IS-95, W-CDMA, IS-2000, the forward link and the reverse link are allocated separate frequencies.

[1006] An example of a data only communication system is a high data rate (HDR) communication system that conforms to the TIA/EIA/IS-856 industry standard, hereinafter referred to as the IS-856 standard. This HDR system is based on a communication system disclosed in co-pending application serial number 08/963,386, entitled "METHOD AND APPARATUS FOR HIGH RATE PACKET DATA TRANSMISSION," filed 11/3/1997, assigned to the assignee of the present invention. The HDR communication system defines a set of data rates, ranging from 38.4 kbps to 2.4 Mbps, at which an access point (AP) may send data to a subscriber station (access terminal, AT). Because the AP is analogous to a base station, the terminology with respect to cells and sectors is the same as with respect to voice systems.

[1007] In a wireless communication system, maximizing a capacity of the communication system in terms of the number of simultaneous telephone calls that can be handled is extremely important. The capacity in a spread spectrum communication system can be maximized if the transmission power of each subscriber station is controlled such that each transmitted signal arrives at a base station receiver at the same signal level. However, if a signal transmitted by a subscriber station arrives at the base station receiver at a power level that is too low, quality communications cannot be achieved due to interference from the other subscriber stations. On the other hand, if the subscriber station transmitted signal is at a power level that is too high when received at the base station, communication with this particular subscriber station is acceptable but this high power signal acts as interference to other

subscriber stations. This interference may adversely affect communications with other subscriber stations. Therefore, each subscriber station needs to transmit the minimum signal level expressed as e.g., a signal-to-noise ratio, that allows transmitted data recovery.

[1008] Consequently, the transmission power of each subscriber station within the coverage area of a base station is controlled by the base station to produce the same nominal received signal power or a signal to noise ratio at the base station. In an ideal case, the total signal power received at the base station is equal to the nominal power received from each subscriber station multiplied by the number of subscriber stations transmitting within the coverage area of the base station plus the power received at the base station from subscriber stations in the coverage area of neighboring base stations.

[1009] The path loss in the radio channel can be characterized by two separate phenomena: average path loss and fading. The forward link, from the base station to the subscriber station, operates on a different frequency than the reverse link, from the subscriber station to the base station. However, because the forward link and reverse link frequencies are within the same general frequency band, a significant correlation between the average path losses of the two links exists. On the other hand, fading is an independent phenomenon for the forward link and reverse link and varies as a function of time.

[1010] In an exemplary CDMA system, each subscriber station estimates the path loss of the forward link based on the total power at the input to the subscriber station. The total power is the sum of the power from all base stations operating on the same frequency assignment as perceived by the subscriber station. From the estimate of the average forward link path loss, the subscriber station sets the transmit level of the reverse link signal. This type of an open loop control is advantageous when there is a correlation between a forward link and a reverse link. Should the reverse link channel for one subscriber station suddenly improve compared to the forward link channel for the same subscriber station due to independent fading of the two channels, the signal as received at the base station from this subscriber station would increase in power. This increase in power causes additional interference to all signals sharing the same frequency assignment. Thus a rapid response of the

subscriber station transmit power to the sudden improvement in the channel would improve system performance. Therefore, it is necessary to have the base station continually contribute to the power control mechanism of the subscriber station. Such a power control mechanism relies on a feedback, also referred to as a closed loop.

[1011] Each base station with which the subscriber station is in communication measures the received signal strength from the subscriber station. The measured signal strength is compared to a desired signal strength level for that particular subscriber station. A power adjustment command is generated by each base station and sent to the subscriber station on the forward link. In response to the base station power adjustment command, the subscriber station increases or decreases the subscriber station transmit power by a predetermined amount. By this method, a rapid response to a change in the channel is effected and the average system performance is improved. Note that in a typical cellular system, the base stations are not intimately connected and each base station in the system is unaware of the power level at which the other base stations receive the subscriber station's signal.

[1012] When a subscriber station is in communication with more than one base station, power adjustment commands are provided from each base station. The subscriber station acts upon these multiple base station power adjustment commands to avoid transmit power levels that may adversely interfere with other subscriber station communications and yet provide sufficient power to support communication from the subscriber station to at least one of the base stations. This power control mechanism is accomplished by having the subscriber station increase its transmit signal level only if every base station with which the subscriber station is in communication requests an increase in power level. The subscriber station decreases its transmit signal level if any base station with which the subscriber station is in communication requests that the power be decreased. A system for base station and subscriber station power control is disclosed in U.S. Pat. No. 5,056,109 entitled "METHOD AND APPARATUS FOR CONTROLLING TRANSMISSION POWER IN A CDMA CELLULAR MOBILE TELEPHONE SYSTEM," issued Oct. 8, 1991, assigned to the Assignee of the present invention.

[1013] There is a relationship between a transmission power and a rate of data to be transmitted. Communication systems, in general, do not allow an instantaneous change of rate of data. If a transmission channel link condition change, resulting in a need to change a transmission power and a data rate during the interval when a rate of data cannot be changed, the transmitted data may be erased. Therefore, there is a need in the art to estimate a rate of data that can be transmitted without an erasure under all channel conditions, or alternatively to estimate power required for transmission of a data at a rate of data.

SUMMARY

[1014] In one aspect of the invention, the above-stated needs are addressed by determining at a source of data a quality metric of a link over which data is to be transmitted and modifying said quality metric by a quality metric margin. The maximum rate of data is then determined in accordance with said modified quality metric. Alternatively, power required for transmission of a data at a rate of data is determined in accordance with said modified quality metric and a rate of the data

[1015] In another aspect of the invention, the quality metric is modified by a pre-determined quality metric margin. Alternatively, modifying said quality metric by a quality metric margin is achieved by declaring an outage event when power required for transmission of a second reference signal exceeds power required for transmission of the second reference signal determined form previously modified quality metric; detecting occurrence of the outage event during a pre-determined interval; and modifying said quality metric in accordance with said detecting.

[1016] In another aspect of the invention, the outage is detected by determining at a source of data a quality metric of a link over which data is to be transmitted; modifying said quality metric by a quality metric margin; and declaring an outage event when power required for transmission of a reference signal exceeds power required for transmission of the reference signal determined form the modified quality metric. Alternatively, the outage is

dedected by determining at a source of data a quality metric of a link over which data is to be transmitted; modifying said quality metric by a quality metric margin; determining a maximum rate of data in accordance with said modified quality metric; and declaring an outage event when power required for transmission of data at the maximum rate of data exceeds maximum allowable transmission power.

BRIEF DESCRIPTION OF THE DRAWINGS

[1017] **FIG.1** illustrates a conceptual diagram of an HDR communication system;

[1018] **FIG. 2** illustrates an exemplary forward link waveform;

[1019] **FIG. 3** illustrates a conceptual arrangement of reverse link transmission power control;

[1020] **FIG. 4** illustrates a conceptual diagram of a reverse link quality estimator;

[1021] **FIG. 5** illustrates a method for transmit power limiting;

[1022] **FIG. 6** illustrates a conceptual arrangement of an embodiment of reverse link maximum admissible data rate estimation;

[1023] **FIG. 7** illustrates a conceptual diagram of a predictor;

[1024] **FIG. 8** illustrates a conceptual operation of a peak filter;

[1025] **FIG. 9** illustrates an exemplary reverse link waveform;

[1026] **FIG. 10** illustrates a conceptual arrangement of another embodiment of reverse link maximum admissible data rate estimation; and

[1027] **FIG. 11** illustrates an outage event detector in accordance with one embodiment.

DETAILED DESCRIPTION

Definitions

[1028] The word “exemplary” is used exclusively herein to mean “serving as an example, instance, or illustration.” Any embodiment described

herein as "exemplary" is not necessarily to be construed as preferred or advantageous over other embodiments.

[1029] The term access network is used exclusively herein to mean a collection of access points (AP) and one or more access point controllers. The access network transports data packets between multiple access terminals (AT). The access network may be further connected to additional networks outside the access network, such as a corporate intranet or the Internet, and may transport data packets between each access terminal and such outside networks.

[1030] The term base station, referred to herein as an AP in the case of an HDR communication system, is used exclusively herein to mean the hardware with which subscriber stations communicate. Cell refers to the hardware or a geographic coverage area, depending on the context in which the term is used. A sector is a partition of a cell. Because a sector has the attributes of a cell, the teachings described in terms of cells are readily extended to sectors.

[1031] The term subscriber station, referred to herein as an AT in the case of an HDR communication system, is used exclusively herein to mean the hardware with which an access network communicates. An AT may be mobile or stationary. An AT may be any data device that communicates through a wireless channel or through a wired channel, for example using fiber optic or coaxial cables. An AT may further be any of a number of types of devices including but not limited to PC card, compact flash, external or internal modem, or wireless or wireline phone. An AT that is in the process of establishing an active traffic channel connection with an AP is said to be in a connection setup state. An AT that has established an active traffic channel connection with an AP is called an active AT, and is said to be in a traffic state.

[1032] The term communication channel/link is used exclusively herein to mean a single route over which a signal is transmitted described in terms of modulation characteristics and coding, or a single route within the protocol layers of either the AP or the AT.

[1033] The term reverse channel/link is used exclusively herein to mean a communication channel/link through which the AT sends signals to the AP.

[1034] A forward channel/link is used exclusively herein to mean a communication channel/link through which an AP sends signals to an AT.

[1035] The term soft hand-off is used exclusively herein to mean a communication between a subscriber station and two or more sectors, wherein each sector belongs to a different cell. In the context of IS-95 standard, the reverse link communication is received by both sectors, and the forward link communication is simultaneously carried on the two or more sectors' forward links. In the context of the IS-856 standard, data transmission on the forward link is non-simultaneously carried out between one of the two or more sectors and the AT.

[1036] The term erasure is used exclusively herein to mean failure to recognize a message.

[1037] The term outage is used exclusively herein to mean a time interval during which the likelihood that a subscriber station will receive service is reduced.

Description

[1038] **FIG.1** illustrates a conceptual diagram of a communication system capable of performing maximum rate of data estimation in accordance with embodiments of the present invention. Various aspects of the maximum rate of data estimation will be described in the context of a CDMA communications system, specifically a communication system in accordance with the IS-856 standard. However, those of ordinary skills in the art will appreciate that the aspects of the maximum rate of data estimation are likewise suitable for use in various other communications environments. Accordingly, any reference to a CDMA communications system is intended only to illustrate the inventive aspects of the present invention, with the understanding that such inventive aspects have a wide range of applications.

[1039] In the above-mentioned communication system, an AP **100** transmits data to an AT **104** over a forward link **106(1)**, and receives data from the AT **104** over a reverse link **108(1).** Similarly, an AP **102** transmits data to the AT **104** over a forward link **106(2)**, and receives data from the AT **104** over a reverse link **108(2)**. In accordance with one embodiment, data transmission on

the forward link occurs from one AP to one AT at or near the maximum data rate that can be supported by the forward link and the communication system. Other channels of the forward link, e.g., control channel, may be transmitted from multiple APs to one AT. Reverse link data communication may occur from one AT to one or more APs. The AP **100** and the AP **102** are connected to a controller **110** over backhauls **112(1)** and **112(2)**. The term backhaul is used to mean a communication link between a controller and an AP. Although only two AT's and one AP are shown in **FIG. 1**, one of ordinary skill in the art recognizes that this is for pedagogical purposes only, and the communication system can comprise plurality of AT's and AP's.

[1040] Initially, the AT **104** and one of the AP's, e.g., the AP **100**, establish a communication link using a predetermined access procedure. In this connected state, the AT **104** is able to receive data and control messages from the AP **100**, and is able to transmit data and control messages to the AP **100**. The AT **104** continually searches for other APs that could be added to the AT **104** active set. The active set comprises a list of the APs capable of communication with the AT **104**. When such an AP is found, the AT **104** calculates a quality metric of the AP's forward link, which in one embodiment comprises a signal-to-interference and-noise ratio (SINR). In one embodiment, the AT **104** searches for other APs and determines the AP's SINR in accordance with a pilot signal. Simultaneously, the AT **104** calculates the forward link quality metric for each AP in the AT **104** active set. If the forward link quality metric from a particular AP is above a predetermined add threshold or below a predetermined drop threshold for a predetermined period of time, the AT **104** reports this information to the AP **100**. Subsequent messages from the AP **100** direct the AT **104** to add to or to delete from the AT **104** active set the particular AP.

[1041] The AT **104** selects a serving AP from the active set based on a set of parameters. The term serving AP refers to an AP that a particular AT selected for data communication or an AP that is communicating data to the particular AT. The set of parameters can comprise present and previous SINR measurements, a bit-error-rate and/or a packet-error-rate, and other parameters known to one skilled in the art. In one embodiment, the serving AP is selected in accordance with the largest SINR measurement. The AT **104** then specifies

the selected AP in a data request message (DRC message), transmitted on the data request channel (DRC channel). The DRC message can contain the requested data rate or, alternatively, an indication of the quality of the forward link, e.g., the measured SINR, the bit-error-rate, or the packet-error-rate. In one embodiment, the AT **104** can direct the transmission of the DRC message to a specific AP by the use of a Walsh code, which uniquely identifies the specific AP. The DRC message symbols are tensor-multiplied (shaped) with the unique Walsh code. The tensor-multiplication (shaping) operation is referred to as Walsh covering of a signal. Since each AP in the active set of the AT **104** is identified by a unique Walsh code, only the selected AP which correlates the DRC signal with the correct Walsh code can correctly decode the DRC message.

[1042] The data to be transmitted to the AT **104** arrive at the controller **110**. In accordance with one embodiment, the controller **110** sends the data to all APs in AT **104** active set over the backhaul **112**. In another embodiment, the controller **110** first determines, which AP was selected by the AT **104** as the serving AP, and then sends the data to the serving AP. The data are stored in a queue at the AP(s). A paging message is then sent by one or more APs to the AT **104** on respective control channels. The AT **104** demodulates and decodes the signals on one or more control channels to obtain the paging messages.

[1043] At each time time-slot, the AP can schedule data transmission to any of the ATs that received the paging message. An exemplary method for scheduling transmission is described in U.S. Patent No. 6,229,795, entitled "SYSTEM FOR ALLOCATING RESOURCES IN A COMMUNICATION SYSTEM," assigned to the assignee of the present invention. The AP uses the rate control information received from each AT in the DRC message to efficiently transmit forward link data at the highest possible rate. In one embodiment, the AP determines the data rate at which to transmit the data to the AT **104** based on the most recent value of the DRC message received from the AT **104**. Additionally, the AP uniquely identifies a transmission to the AT **104** by using a spreading code which is unique to that mobile station. In the exemplary embodiment, this spreading code is the long pseudo noise (PN) code, which is defined by the IS-856 standard.

[1044] The AT **104**, for which the data packet is intended, receives the data transmission and decodes the data packet. In one embodiment, each data packet is associated with an identifier, e.g. a sequence number, which is used by the AT **104** to detect either missed or duplicate transmissions. In such an event, the AT **104** communicates via the reverse link data channel the sequence numbers of the missing data units. The controller **110**, which receives the data messages from the AT **104** via the AP communicating with the AT **104,** then indicates to the AP what data units were not received by the AT **104**. The AP then schedules a retransmission of such data units.

[1045] One skilled in the art recognizes that an AP can comprise one or more sectors. In the description above, the term AP was used generically to allow clear explanation of basic concepts of the HDR communication system. However, one skilled in the art can extend the explained concepts to AP comprising any number of sectors. Consequently, the concept of sector will be used throughout the rest of the document.

Forward Link Structure

FIG. 2 illustrates an exemplary forward link waveform **200**. For pedagogical reasons, the waveform **200** is modeled after a forward link waveform of the above-mentioned HDR system. However, one of ordinary skill in the art will understand that the teaching is applicable to different waveforms. Thus, for example, in one embodiment the waveform does not need to contain pilot signal bursts, and the pilot signal can be transmitted on a separate channel, which can be continuous or bursty. The forward link **200** is defined in terms of frames. A frame is a structure comprising 16 time-slots **202**, each time-slot **202** being 2048 chips long, corresponding to a 1.66. ms. time-slot duration, and, consequently, a 26.66. ms. frame duration. Each time-slot **202** is divided into two half-time-slots **202a**, **202b**, with pilot bursts **204a**, **204b** transmitted within each half-time-slot **202a**, **202b**. In the exemplary embodiment, each pilot burst **204a**, **204b** is 96 chips long, and is centered at the mid-point of its associated half-time-slot **202a**, **202b**. The pilot bursts **204a**, **204b** comprise a pilot channel signal covered by a Walsh cover with index 0. A forward medium access control channel (MAC) **206** forms two bursts, which are transmitted immediately

before and immediately after the pilot burst **204** of each half-time-slot **202**. In the exemplary embodiment, the MAC is composed of up to 64 code channels, which are orthogonally covered by 64-ary Walsh codes. Each code channel is identified by a MAC index, which has a value between 1 and 64, and identifies a unique 64-ary Walsh cover. A reverse power control channel (RPC) is used to regulate the power of the reverse link signals for each subscriber station. The RPC commands are generated by comparing measured reverse link transmission power at the base station with a power control set point. If the measured reverse link transmission power is below the set point, then an RPC up command is provided to the subscriber station to increase the reverse link transmission power. If the measured reverse link transmission power is above the set point, then an RPC down command is provided to the subscriber station to decrease the reverse link transmission power. The RPC is assigned to one of the available MACs with MAC index between 5 and 63. The MAC with MAC index 4 is used for a reverse activity channel (RA), which performs flow control on the reverse traffic channel. The forward link traffic channel and control channel payload is sent in the remaining portions **208a** of the first half-time-slot **202a** and the remaining portions **208b** of the second half-time-slot **202b**.

Reverse Link Power Control

[1046] Unlike the forward link, whose channels are always transmitted at full available power, the reverse link comprises channels, whose transmission is power controlled, to achieve the goal of maximized capacity of the communication system as explained above. Consequently, aspects of the maximum rate of data estimation will be described in the context of the reverse link. However, as those of ordinary skills in the art will readily appreciate, these aspects are equally applicable to a forward link in a communication system, whose forward link is also power controlled.

[1047] The reverse link transmission power of the communication system in accordance with the IS-856 standard is controlled by two power control loops, an open loop and a closed loop. Conceptual arrangement of the open loop and closed loop is illustrated in **FIG. 3**. The first power control loop is an open loop control. The open loop generates an estimate of the reverse link

quality metric in block **302**. In one embodiment, the quality metric is a path loss. The estimated path loss is then translated into a required transmit power (TxOpenLoopPwr) in accordance with other factors, e.g., a base station loading. In one embodiment, illustrated in **FIG. 4**, block **302** (of **FIG. 3**) comprises a filter **302** filtering a received signal power RxPwr. The filtered RxPwr is provided to block **304** together with a parameter K providing compensation for base station loading and translation to the TxOpenLoopPwr. In one embodiment, the block **304** combines the filtered RxPwr and the parameter K in accordance with an Equation (1):

$$TxOpenLoopPwr = K - F(RxPwr) \tag{1}$$

where F is the transfer function of the filter **302**.

In one embodiment, the received signal is a signal received on a pilot channel. One of ordinary skills in the art recognizes that other embodiments of an open loop estimation process are well known the art and are equally applicable.

[1048] Referring back to **FIG. 3**, the function of the closed loop is to correct the open loop estimate, which does not take into account environmentally induced phenomena, such as shadowing, and other user interferences, to achieve a desired quality signal quality at the base station. In one embodiment, the desired signal quality comprises a signal-to-noise ratio (SNR). The objective can be achieved by measuring the quality metric of a reverse link and reporting results of the measurement back to the subscriber station. In one embodiment, the base station measures a reference signal transmitted over the reverse link, and provides feedback to the subscriber station. The subscriber station adjust the reverse link transmission power in accordance with the feedback signal. In one embodiment, the reference signal comprises a pilot SNR, and the feedback comprises the RPC commands, which are summed in a summer **304** and scaled to obtain the required closed loop transmit power (TxClosedLoopAdj). Like the open loop, the closed loop is well known the art and other known embodiments are equally applicable, as recognized by one of ordinary skills in the art.

[1049] The TxOpenLoopPwr and the TxClosedLoopAdj are summed in a block **306** to yield TxPilotPwr. The value of the TxPilotPwr is, in

general, different from the value of total transmit power required for transmission of a desired reverse link rate of data (rlRate). Consequently, the TxPilotPwr needs to be adjusted for the required rlRate. This is accomplished by translating the rlRate to a power in block **308**, and combining the result of the translation with the TxPilotPwr in a block **310** to yield the total transmit power (TxTotalPwr). Consequently, the TxTotalPwr can be expressed by an Equation 2:

$$\text{TxTotalPwr} = \text{TxOpenLoopPwr} + \text{TxClosedLoopAdj} + \text{PilotToTotalRatio}(\text{rlRate}) \quad (2)$$

where the PilotToTotalRatio is a function describing a translation between the rate of data of a signal used for determining the TxOpenLoopPwr and the TxClosedLoopAdj and the rlRate.

[1050] Because a transmitter implementation has maximum allowable power (TxMaxPwr), the TxTotalPwr may be optionally limited in block **312**. In one embodiment, the transmit power limiting is performed in accordance with a method illustrated in **FIG. 5**. The method starts in step **502** and continues in step **504**. In step **504**, the TxTotalPwr is compared to the TxMaxPwr. If the TxTotalPwr is less or equal to TxMaxPwr, the method continues in step **506**, where the TxPwrLimited is set equal to TxMaxPwr; otherwise, the method continues in step **508**, where the TxPwrLimited is set equal to TxTotalPwr. The method ends in step **510**.

[1051] As follows from the above-described power control method if the TxTotalPwr is greater than the TxMaxPwr, the transmitted power is limited to the TxMaxPwr. Consequently, there is no assurance, that the data transmitted will be successfully received and decoded at the BS. Consequently, a maximum admissible rate of data estimator is included in the power control loop as described in the embodiments below.

Maximum Admissible Data Rate Estimation

[1052] **FIG. 6** illustrates a conceptual arrangement of reverse link maximum admissible rate of data estimation. The open loop generates an estimate of the reverse link quality metric in block **602**. In one embodiment, the

quality metric is a path loss. The estimated path loss is then translated into a required transmit power TxOpenLoopPwr in accordance with other factors, e.g., a base station loading. In one embodiment, the TxOpenLoopPwr is estimated in accordance with **FIG. 4**. The TxOpenLoopPwr is provided to a block **604**, which may predict the value of TxOpenLoopPwr at some time in the future. The output of the predicted is denoted TxOpenLoopPred. In one embodiment, the block **604** is an identity function; consequently, the TxOpenLoopPwr is unaffected by the block **604**, therefore, TxOpenLoopPred = TxOpenLoopPwr. Another embodiment of the block **604** is illustrated in **FIG. 7**.

[1053] As illustrated in **FIG. 7**, TxOpenLoopPwr is provided to a linear, time-invariant filter **7102**. In one embodiment, the filter **702** is a low pass filter. In another embodiment, the filter **702** has a transfer function $F_1 = 1$; consequently, the TxOpenLoopPwr is unaffected by the filter **702**. The TxOpenLoopPwr filtered by a filter **702** is provided to a filter **704**. In one embodiment, the filter **704** is a peak filter. The function of the peak filter is explained in reference to **FIG. 8**.

[1054] Referring to **FIG. 8**, at time t_0, the Input signal is provided to a peak filter. The value of the output of the peak filter Output signal is initialized to the value of Input signal. From time t_0 to time t_1, the Output signal tracks the Input signal. At time t_1, the Input signal reached a peak and started to decay. The Output signal stopped to follow the Input signal, and started to decay by a pre-determined rate. At time t_2, the Input signal became equal to the Output signal and continued to rise. Consequently, the Output signal stops decaying, and starts tracking the Input signal.

[1055] Referring back to **FIG. 6**, the TxOpenLoopPred is provided to a combiner block **610**. In one embodiment the combiner block **610** comprises a summer summing the TxOpenLoopPred with a prediction of the closed loop adjustment (TxClosedLoopPred), to yield a prediction of transmit pilot power (TxPilotPred). The predicted closed loop adjustment TxClosedLoopPred is estimated by providing a feedback signals for the closed loop to a block **606**. In one embodiment, the feedback signal comprises the RPC commands; consequently, the block **606** comprises a summer. The output of the summer represents the estimate of correction to the open loop estimated transmit power (TxClosedLoopAdj). The TxClosedLoopAdj is provided to a block **608**. In one

embodiment, the block **608** comprises a filter as described in reference to **FIG. 7**, i.e., an optional low pass filter **702** and a (non-optional) peak filter **704**. In accordance with one embodiment, the pre-determined decay rate of the peak filter **704** is 0.5 dB per a frame of signal. The peak filter is initialized as follows. One of the ATs and one of the APs establish a communication link using a predetermined access procedure, as part of which the RPC channel is established. Assuming that the RPC channel was established at time t_0 (referring to **Fig. 8**) the RPC commands are being provided to the block **608,** and consequently to the peak filter **704.** The TxClosedLoopPred (the Output signal of **Fig. 8**) is then initialized to the value of TxClosedLoopAdj (the Output signal of **Fig. 8**) at the time t_0.

[1056] Referring back to the block **610**, the TxPilotPred is provided to a combiner block **612**. Combiner block **612** also accepts a transmission power margin (TxPwrMargin). In one embodiment, (not shown) the TxPwrMargin is a constant, with default value of 3 dB. In another embodiment, the TxPwrMargin is dynamically adjusted by block **614**, in accordance with outage events. The method for dynamically adjusting the TxPwrMargin is described in detail below. Referring back to the combiner block **612**, in one embodiment, the combiner block **612** is a summer, consequently the output, a bounded transmission pilot signal (TxPilotUpperBound) is given by an Equation (3):

$$\text{TxPilotUpperBound}=\text{TxOpenLoopPred}+\text{TxClosedLoopPred}+\text{TxPwrMargin} \qquad (3)$$

The value of the TxPilotPred is, in general, different from the value of total transmit power required for transmission of a desired reverse link rate of data (rlRate). Consequently, the TxPilotUpperBound needs to be adjusted for the required rlRate. This is accomplished by translating the rlRate to a power in block **616**, and is combining the result of the translation with the TxPilotUpperBound in a block **618** to yield the bounded total transmit power. A given rlRate is considered to be admissible if an Equation (4) is satisfied:

$$\text{TxPilotUpperBound} + \text{PilotToTotalRatio(rlRate)} < \text{TxMaxPwr} \qquad (4)$$

[1057] To optimize a performance of a communication system, it is desired that the highest data rate (rlRatePredicted), which is admissible (according to the Equation(4) is determined. Consequently, the TxTotalPwrUpperBound is compared with the maximum power available for transmission (TxMaxPwr) in block **620**. Thus, the block **620** evaluates the Equation (4). The result of the comparison is provided to a block **622**. If the Equation (4) is satisfied, the block **622** selects rlRate higher than the rlRate that has just been tested, provides the selected rlRate to the block **616**, and the process is repeated until the Equation (4) does not hold. The highest rate, for which the Equation (4) is satisfied is outputted as rlRatePredicted. One of ordinary skills in the art understands that the blocks **618** – **622** can be implemented or performed with a general purpose processor, a digital signal processor (DSP), an application specific integrated circuit (ASIC), a field programmable gate array (FPGA) or other programmable logic device, discrete gate or transistor logic, discrete hardware components, or any combination thereof designed to perform the functions described herein. For the purposes of this document any of the above-enumerated options is referred to collectively as a processing block.

Estimation of Power Required for Transmission of Data at a Rate of Data

[1058] Alternatively, the apparatus as illustrated in **FIG. 6** may be utilized for estimating power required for transmission of data at a pre-determined rate. In such an embodiment, the pre-determined rlRate yields a value of TxTotalPowerUpperBound as described above. The TxTotalPwrUpperBound can be then outputted (not shown). Alternatively, the TxTotalPwrUpperBound may be compared with one or more thresholds, and the result may be used, for example, to control the state of the power amplifier, to improve the energy efficiency of the transmitter (communication device). Thus, the TxTotalPwrUpperBound is compared with the one or more thresholds in block **620**. Thus, the block **620** evaluates the Equation (4). The result of the comparison is provided to a block **622**. The block **620** provides an indication whether the Equation (4) is satisfied to block **622**, which provides an appropriate output, e.g., the value of the pre-determined rlRate, the corresponding threshold

and indication whether the Equation (4) is satisfied or not. If desired, the process is repeated for all available rlRates, and thresholds.

TxPwrMrg Dynamic Adjustment

[1059] As discussed, the reverse link channel comprises the Physical Layer Channels transmitted from the AT to the access network. **FIG. 9** illustrates an exemplary reverse link waveform **900**. For pedagogical reasons, the waveform **900** is modeled after a reverse link waveform of the above-mentioned system in accordance to IS-856 standard. However, one of ordinary skill in the art will understand that the teaching is applicable to different waveforms. The reverse link channel **900** is defined in terms of frames **902**. A frame is a structure comprising 16 time-slots **904(n)**, each time-slot **904(n)** being 2048 chips long, corresponding to a 1.66. ms. time-slot duration, and, consequently, a 26.66. ms. frame duration.

[1060] In accordance with the IS-856 standard, the rate of data can change only at a frame boundary. In general, the value of rlRatePredicted will be determined several slots before the start of a frame, in order to arrive at the rate of data to be transmitted during that frame on the reverse link. Suppose the value of rlRatePredicted is determined at time t_0, k slots (k > 0) before the start of a frame **902(m)**in accordance with the above-described embodiment. At the start of the frame **902(m)**, the AT evaluates the transmit power requirement for the determined rlRatePredicted in accordance with the open loop and closed loop power control, and begins transmitting the data. During the frame duration, the transmit power is adjusted in accordance with update of the open loop and closed loop power control. Consequently, the actual transmit power may differ from the transmit power TxTotalPowerUpperBound, corresponding to the determined rlRatePredicted. To evaluate the performance of the maximum admissible data rate estimation, the concept of outage can be utilized.

[1061] The n^{th} slot the **902(m^{th})** frame is defined to be in outage of Type A if the power required for the rlRatePredicted at the n^{th} slot is greater than the power determined for the rlRatePredicted at time t_0, i.e., if an Equation (5) is satisfied:

$$\text{TxOpenLoop}[16m+n]+\text{TxClosedLoop}[16m+n]+\text{PilotToTotalRatio}(\text{rlRatePredicted}[16m-k])>\text{TxMaxPwr} \tag{5}$$

If the nth slot of the **902(mth)** frame is not in outage of Type A, then from Equations (4) and (5) follows:

$$\text{TxPilotPred}[16m+n] + \text{PilotToTotaRatiol}(\text{rlRatePredicted}[16m-k]) \leq \text{xPwrMargin} \quad (6)$$

[1062] The nth slot of the **902(mth)** frame is defined to be in outage of Type B if the power required for the rlRatePredicted at the nth slot is greater than the power determined for the rlRatePredicted at time t_0, i.e., if an Equation (7) is satisfied:

$$\text{TxPilotUpperBound}[16m + n] > \text{TxPilotUpperBound}[16m - k],\ n = 0, 1, \ldots, 15 \quad (7)$$

If the nth slot of the **902(mth)** frame is not in outage of Type B, then from Equations (4) and (7) follows:

$$\text{TxPilotPred}[16m+n]+\text{PilotToTotalRatio}(\text{rlRatePredicted}[16m-k]) \leq \text{TxMaxPwr} \quad (8)$$

[1063] Equations (6) and (8) shows that if the value of rlRatePredicted determined at time t_0 is used for transmitting the data over the next frame **902(m+1)**, then the reverse link is not power-limited during the nth slot of the frame **902(m+1).**

[1064] It has been discovered, that due to various methods for mitigating changing channel conditions, e.g., error correction, interleaving and other methods known to one of ordinary skills in the art, isolated slot outages in a frame do not result in packet decoding errors, however too many slot outages in one frame result in packet decoding errors. A design goal of a communication system is to limit the slot outage probability, to guarantee minimal performance degradation due to packet errors, while maximizing reverse link throughput under all channel conditions. From Equations (3), (4), (6) and (8) that increasing TxPwrMargin may reduce outage probability, while reducing TxPwrMargin increases the predicted reverse link data rate. In other words, a large value of TxPwrMargin provides a conservative estimate of the predicted reverse link data rate, resulting in lower user throughput and possibly,

diminished reverse link capacity. Therefore, in another embodiment, the value of TxPwrMargin is dynamically adjusted in accordance with changing channel conditions in order to maintain outage probability at the desired value.

[1065] In one embodiment, of dynamically adjusting the TxPwrMargin, an occurrence of an outage is evaluated for each slot of the frame **902(m+1)**. If a slot outage occurs, the TxPwrMargin is incremented by PwrMarginUpStep; otherwise, the TxPwrMargin is decremented by PwrMarginDownStep. In one embodiment, the TxPwrMarginUpStep = 0.5 dB, the TxPwrMarginDownStep = 0.05 dB. The value of TxPwrMargin is further limited between TxPwrMarginMin and TxPwrMarginMax. In one embodiment, the TxPwrMarginMin = 0 dB and TxPwrMarginMax = 6 dB

[1066] In another embodiment, if a frame has j slot outages, 0 <= j <= 16, TxPwrMargin is incremented by TxPowerMarginStep[j], where TxPowerMarginStep[] is an array of length 16. Note that several elements of the array TxPowerMarginStep[] can be zeros to allow for the above-mentioned consideration that few, isolated slot outages in a frame do not result in packet decoding errors. The value of TxPwrMargin is further limited between TxPwrMarginMin and TxPwrMarginMax.

Ratchet Mode

[1067] Additionally, when the Type A outage is used for dynamic adjustment of the TxPwrMargin, a special update mode - a ratchet mode - is entered if the determined rlRatePredicted changes from a lower value to a maximum allowable rate of data value (rlRateMaxAllowable), or if the determined rlRatePredicted changes from a higher value to a minimum rate of data (rlRateMinAllowable).

[1068] If the determined rlRatePredicted changes from a lower value to the rlRateMaxAllowable, the lower bound of the power margin (TxPwrMarginLow) is set equal to the current value of TxPwrMargin. If a slot outage occurs, the TxPwrMargin is incremented by PwrMarginUpStep. If no slot outage occurs, an Equation (9) is evaluated:

$$\text{TxPwrMargin} - \text{PwrMarginDownStep} \geq \text{TxPwrMarginLow} \qquad (9)$$

If the Equation (9) is satisfied, the TxPwrMargin is decremented by PwrMarginDownStep; otherwise, the TxPwrMargin is set equal to TxPwrMarginLow. When the determined rlRatePredicted changes from the maximum allowable rate of data value to a lower value, the TxPwrMarginLow is set to TxPwrMarginMin. The ratchet mode is exited when the determined rlRatePredicted drops below the rlRateMaxAllowable.

[1069] If the determined rlRatePredicted changes from a higher value to the rlRateMinAllowable, upper bound of the power margin (TxPwrMarginUpper) is set equal to the current value of TxPwrMargin. If a slot outage occurs, an Equation (10) is evaluated:

$$\text{TxPwrMargin} + \text{PwrMarginUpStep} >= \text{TxPwrMarginUpper} \qquad (10)$$

If the Equation (10) is satisfied, the TxPwrMargin is not changed; otherwise the TxPwrMargin is incremented by PwrMarginUpStep. If a no slot outage occurs the TxPwrMargin is decremented by PwrMarginDownStep. The ratchet mode is exited when the determined rlRatePredicted exceeds the rlRateMinAllowable.

[1070] In another embodiment of the ratchet mode, if rlRatePredicted equals rlRateMaxAllowable, and a slot outage does not occur, then TxPwrMargin is not changed from the current value. If a slot outage occurs, the TxPwrMargin is incremented by a PwrMarginUpStep. If rlRatePredicted equals rlRateMinAllowable, and a slot outage occurs, TxPwrMargin is not changed the current value. If a slot outage does not occur, the TxPwrMargin is decremented by a PwrMarginDownStep.

[1071] **FIG. 11** illustrates an outage event detector **1100**, in accordance with one embodiment. The transmission power of a signal whose outage is to be determined (TxSignal) is provided to a block **1102,** together with the reference signal (TxRefSignal). The block **1102** provides an output when TxSignal is greater than TxRefSignal. In one embodiment, the block **1102** comprises a comparator. The output of the block **1102** is provided to a block **1104**. The block **1104** is further provided with a timing signal from block **1106**. Block **1104** outputs a signal providing information of the number of occurrences of TxSignal being greater than TxRefSignal.

[1072] Those of ordinary skill in the art will recognize that although the various embodiments were described in terms of power control being performed by both an open loop and a closed loop, such was done for pedagogical purposes only. Clearly, any mechanism that allows an AT to estimate a quality metric of a reverse link over which the AT transmits data is sufficient. Therefore, should an AT use only an open loop, or only a closed loop, the embodiments would be equally applicable. Thus, referring to **FIG. 6**, if only an open loop were implemented, (i.e., blocks **606** and **608** were deleted) form **FIG. 6**, the embodiments are valid, realizing that:

$$TxOpenLoopPwr = TxPilotIPwr \quad (11)$$

[1073] Furthermore, in a specific case, when a path loss changes slowly the embodiment described in reference to **FIG. 6** can be further simplified as illustrated in **FIG. 10**, where the function of blocks **1002**, **1006**, **1008**, **1010**, and **1012** is the same as function of blocks **602**, **606**, **608**, **610**, and **612**. One of ordinary skills in the art recognizes, that moving the block **1012** to the closed loop branch did not change determination of TxPilotPredUpperBound because Equation (3) holds.

[1074] Those of ordinary skill in the art will recognize that although the various embodiments were described in terms of flowcharts and methods, such was done for pedagogical purposes only. The methods can be performed by an apparatus, which in one embodiment comprises a processor interfaced with a transmitter and a receiver or other appropriate blocks at the AT and/or AP.

[1075] Those of skill in the art would understand that information and signals may be represented using any of a variety of different technologies and techniques. For example, data, instructions, commands, information, signals, bits, symbols, and chips that may be referenced throughout the above description may be represented by voltages, currents, electromagnetic waves, magnetic fields or particles, optical fields or particles, or any combination thereof.

[1076] Those of skill would further appreciate that the various illustrative logical blocks, modules, circuits, and algorithm steps described in

connection with the embodiments disclosed herein may be implemented as electronic hardware, computer software, or combinations of both. To clearly illustrate this interchangeability of hardware and software, various illustrative components, blocks, modules, circuits, and steps have been described above generally in terms of their functionality. Whether such functionality is implemented as hardware or software depends upon the particular application and design constraints imposed on the overall system. Skilled artisans may implement the described functionality in varying ways for each particular application, but such implementation decisions should not be interpreted as causing a departure from the scope of the present invention.

[1077] The various illustrative logical blocks, modules, and circuits described in connection with the embodiments disclosed herein may be implemented or performed with a general purpose processor, a digital signal processor (DSP), an application specific integrated circuit (ASIC), a field programmable gate array (FPGA) or other programmable logic device, discrete gate or transistor logic, discrete hardware components, or any combination thereof designed to perform the functions described herein. A general purpose processor may be a microprocessor, but in the alternative, the processor may be any conventional processor, controller, microcontroller, or state machine. A processor may also be implemented as a combination of computing devices, e.g., a combination of a DSP and a microprocessor, a plurality of microprocessors, one or more microprocessors in conjunction with a DSP core, or any other such configuration.

[1078] The steps of a method or algorithm described in connection with the embodiments disclosed herein may be embodied directly in hardware, in a software module executed by a processor, or in a combination of the two. A software module may reside in RAM memory, flash memory, ROM memory, EPROM memory, EEPROM memory, registers, hard disk, a removable disk, a CD-ROM, or any other form of storage medium known in the art. An exemplary storage medium is coupled to the processor such the processor can read information from, and write information to, the storage medium. In the alternative, the storage medium may be integral to the processor. The processor and the storage medium may reside in an ASIC. The ASIC may

reside in a user terminal. In the alternative, the processor and the storage medium may reside as discrete components in a user terminal.

[1079] The previous description of the disclosed embodiments is provided to enable any person skilled in the art to make or use the present invention. Various modifications to these embodiments will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other embodiments without departing from the spirit or scope of the invention. Thus, the present invention is not intended to be limited to the embodiments shown herein but is to be accorded the widest scope consistent with the principles and novel features disclosed herein.

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[1081] **WHAT IS CLAIMED IS:**